An Approach for the Estimation of Error Rates in Observing Critical Situations

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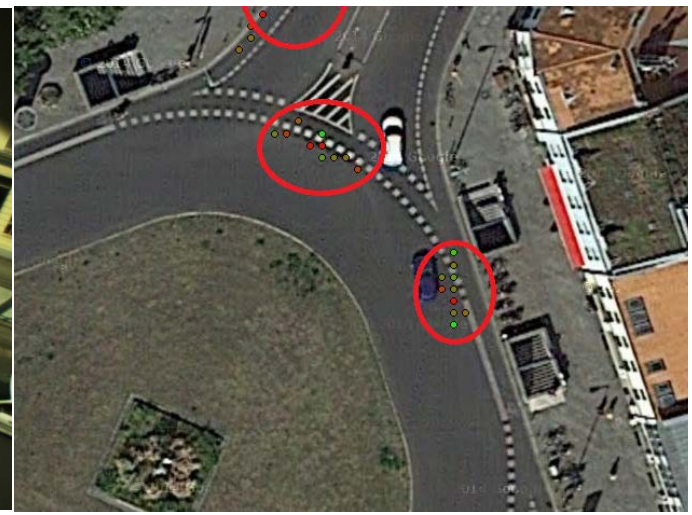
Overview

- Motivation
- Approach
  - Distance and velocity measurement errors
  - TTC error
- Field studies
- Conclusions
- Outlook

Motivation

- SSM widely used to detect critical situations in road traffic:
  - Single critical situations for in-depth analysis
  - Frequency to determine overall safety, find black spots



- BUT: sensors and methods needed to determine the SSM are subject to measurement errors

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Motivation

Evaluate observation quality leading to detection of critical situations (e.g. how many false alarms?)

How many of the detected critical situations (TTC < 1.5s) are truely critical?

Use cases

1. allow practitioners to raise requirements for sensors that are appropriate for the task of detecting a critical situation.

2. allows to estimate the duration of observations

   (Given automated pre-selection of situations, then “How many situations have to be observed to be sure by 99.7% to have n real critical scenes?”)

Main goal

Provide confusion matrix for different measurement error magnitudes:

Look up the **expected false alarm rate for critical situations** depending on the accuracy of your detection system

Approach

- The error rate is influenced by
  1. the measurement errors of velocity, location and object extents estimation
  2. by the statistical distributions of velocity differences and headways of the road users.

Known distribution of speed and distance

Measurement errors of speed and distance

Error of TTC-based detections of critical situations

Time-To-Collision (TTC)

Here we use simple equation of

$$\text{TTC} = -d \,/\, \Delta v,$$

where d is the distance between O_1 and O_2 and $\Delta v = v_2 - v_1$.

Note: assumes no change in behavior/motion

- Constant speed of both traffic participants
- Braking would mean contiuously changing speed …

Probability Density Distribution of TTC in Traffic

Known distribution of speed and distance

Measurement errors of speed and distance

Error of TTC-based detections of critical situations

Data set for distance and velocity difference distribution

- *Intelligent Cruise Control Field Operational Test* (conducted between 1996 and 1997 in Michigan, USA; 8690 trips of 102 drivers adding up to 1821 driving hours and 88,000 driving kilometers)

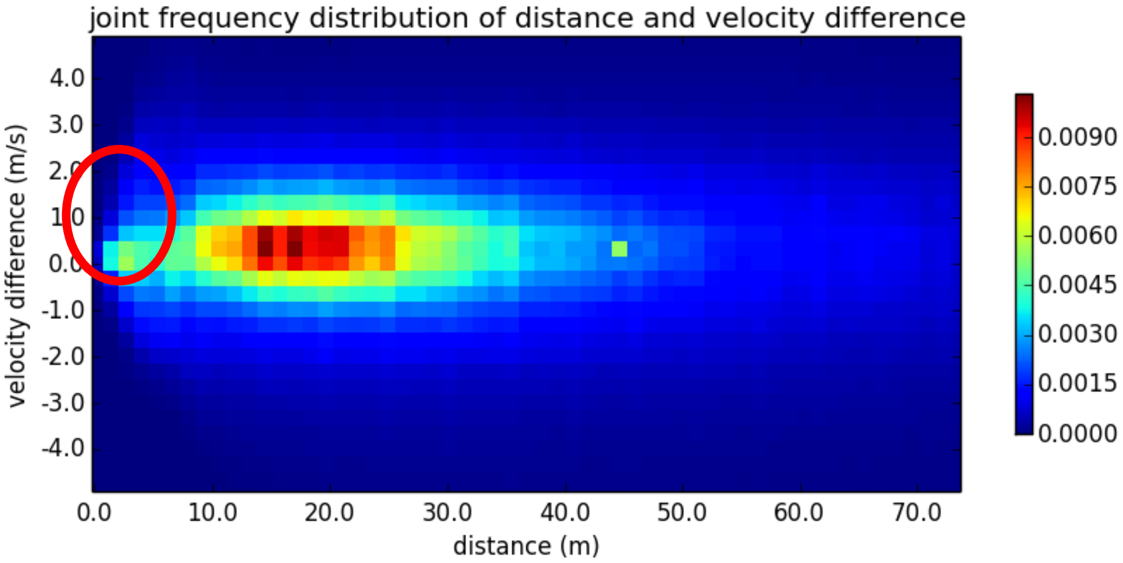


Fig. 1: Joint frequency distribution of distance and velocity difference

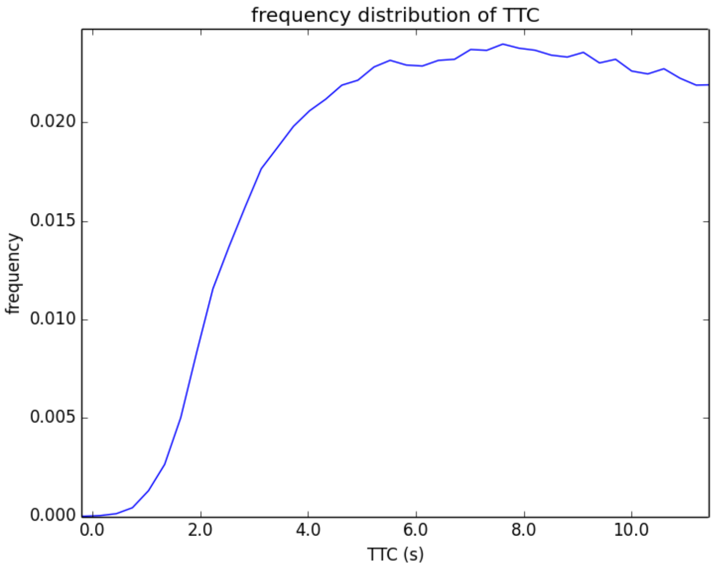
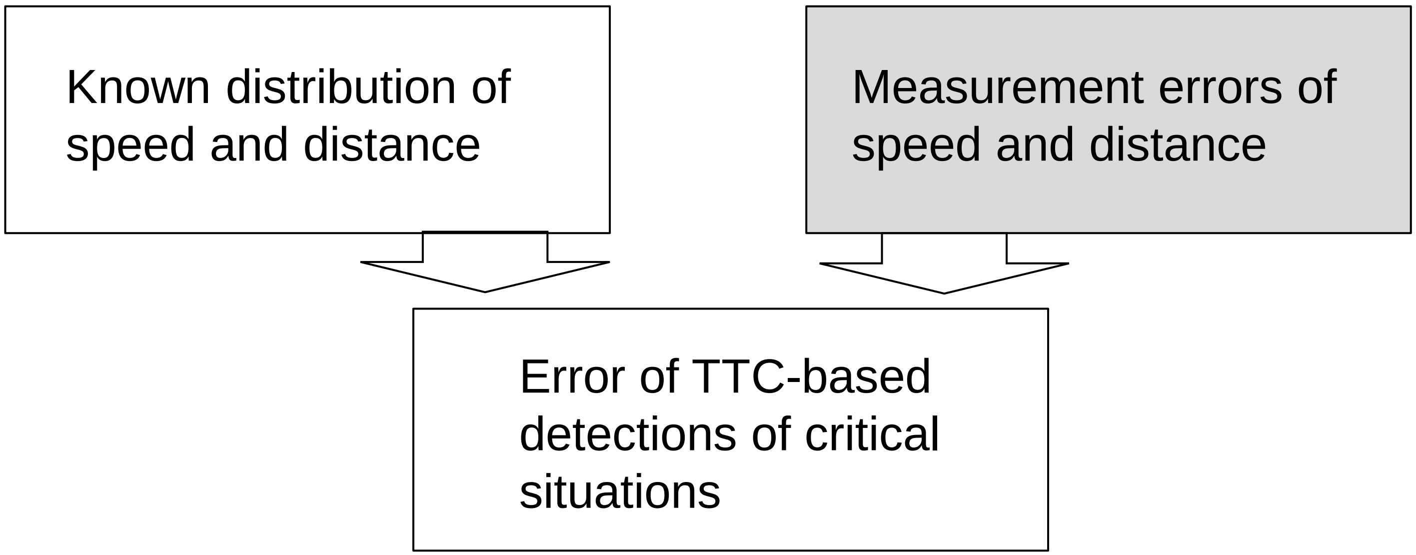


Fig. 2: frequency distribution of only positive TTC values

Error of measurements



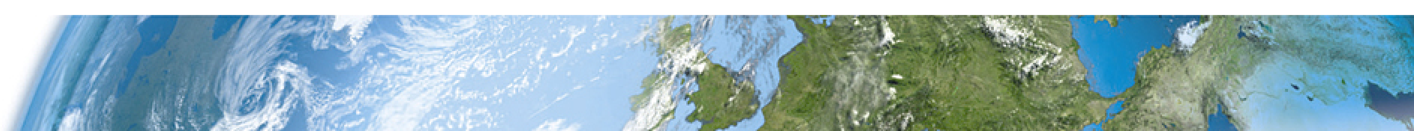
Probability distribution of measured TTC

- Distance and the velocity difference measurement are modeled as two independent Gaussian distributed random variables

(1) $$L(h,k,\gamma) = \frac{1}{2\pi\sqrt{1-\gamma^2}} \int_h^\infty \int_k^\infty \exp\left(-\frac{x^2-2\gamma xy+y^2}{2(1-\gamma^2)}\right) dx\, dy$$

- We get a cumulative distribution function $F(t)$ of the random variable of measuring TTC, which can be interpreted as the probability for measurements truely measuring TTC < t0

(2) $$\begin{aligned} F(t) = \; & L\left(\frac{d^*+t\Delta v^*}{\sigma_d\sigma_{\Delta v}a(t,\sigma_d,\sigma_{\Delta v},\rho_{d,\Delta v})}, \frac{\Delta v}{\sigma_{\Delta v}}, \frac{t\sigma_{\Delta v}-\rho_{d,\Delta v}\sigma_d}{\sigma_d\sigma_{\Delta v}a(t,\sigma_d,\sigma_{\Delta v},\rho_{d,\Delta v})}\right) \\ & + L\left(\frac{-t\Delta v^*-d^*}{\sigma_d\sigma_{\Delta v}a(t,\sigma_d,\sigma_{\Delta v},\rho_{d,\Delta v})}, -\frac{\Delta v}{\sigma_{\Delta v}}, \frac{t\sigma_{\Delta v}-\rho_{d,\Delta v}\sigma_d}{\sigma_d\sigma_{\Delta v}a(t,\sigma_d,\sigma_{\Delta v},\rho_{d,\Delta v})}\right) \end{aligned}$$



Classification of Detection Outcome

- a *true positive* (TP), if the real and the measured TTC value are critical,
- a *false positive* (FP), if the real TTC value is uncritical but the measured TTC value is critical,
- a *true negative* (TN), if the real and the measured TTC value are uncritical,
- a *false negative* (FN), if the real TTC value is critical but the measured TTC value is uncritical.

TTC Error

Known distribution of speed and distance

Measurement errors of speed and distance

Error of TTC-based detections of critical situations

TTC Error

Unnormalized frequency q of true positive detections:

$$q(\mathrm{TP}) = \int_{-\infty}^{0} \int_{0}^{-T_0 x} h(x, y) \underbrace{\left(F_{x,y}(T_0) - F_{x,y}(0)\right)} \, dy \, dx$$

probability of having
a critical TTC value in
real-world traffic

probability, that the
measured TTC value is
critical

TTC Error: Table of Confusion

- Expected outcomes of an automated system detecting critical situations

σ_d in m	σ_v in $\frac{m}{s}$	TTC threshold T_0 in s	$p(\mathrm{TP})$	$p(\mathrm{FP})$	$p(\mathrm{TN})$	$p(\mathrm{FN})$	
0.1	0.01	0.5	0.022	0.009	99.956	0.013	
1.0	0.01	0.5	0.003	0.059	99.906	0.032	
10.0	0.01	0.5	0.000	0.376	99.508	0.035	
0.1	0.1	0.5	0.022	0.010	99.945	0.014	
1.0	0.1	0.5	0.003	0.060	99.905	0.032	
10.0	0.1	0.5	0.000	0.378	99.586	0.035	
0.1	1.0	0.5	0.018	0.052	99.912	0.017	
1.0	1.0	0.5	0.006	0.142	99.823	0.030	
10.0	1.0	0.5	0.001	0.587	99.378	0.035	
0.1	0.01	1.0	0.059	0.005	99.899	0.037	12:1
1.0	0.01	1.0	0.018	0.133	99.770	0.079	
10.0	0.01	1.0	0.002	0.759	99.145	0.095	
0.1	0.1	1.0	0.058	0.007	99.896	0.038	
1.0	0.1	1.0	0.018	0.136	99.768	0.078	
10.0	0.1	1.0	0.002	0.763	99.141	0.095	
0.1	1.0	1.0	0.051	0.232	99.671	0.046	
1.0	1.0	1.0	0.029	0.356	99.547	0.067	1:12
10.0	1.0	1.0	0.004	1.181	98.722	0.093	
0.1	0.01	2.0	[illegible]	[illegible]	[illegible]	[illegible]	

Note: green rows denote combinations with positive TP : FP ration

Experiment - 1

Conducting driving studies for measuring accuracy of computer vision systems

Error of position: σ_x	Error of distance σ_d	Error of velocity σ_v
0.17 m	0.51 m	1.36 m/s

p(TP) = 0.233%, p(FP) = 1.253%, p(TN) = 98.333%, p(FN) = 0.181% (T_0=2.0 s).

$\boxed{\textbf{TP : FP ration is 1 : 5.3}}$

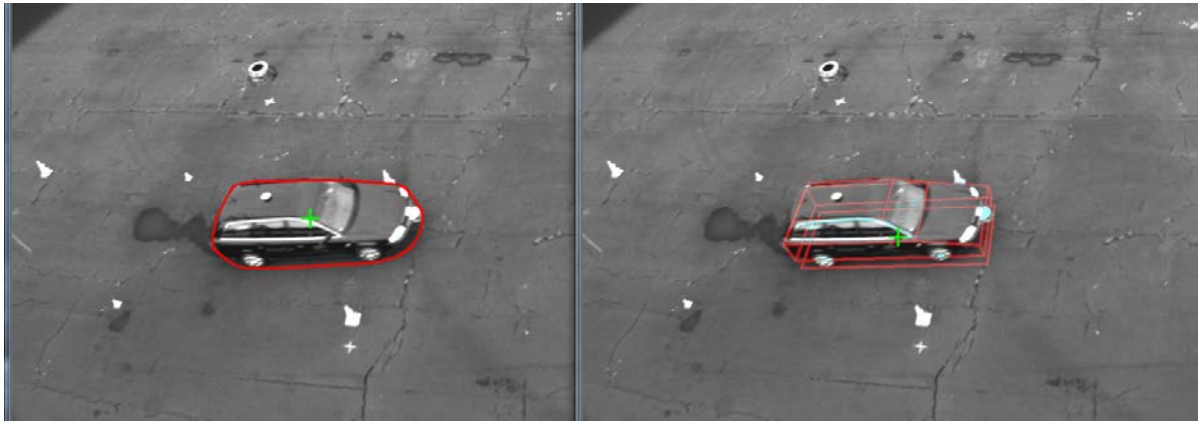


Fig.: Measuring *position error*: compare dGPS measurement and gravity point of wireframe hull; *velocity error* from comparison cars inertial system with velocities from computer vision system (filtered by Extended Kalman Filter)

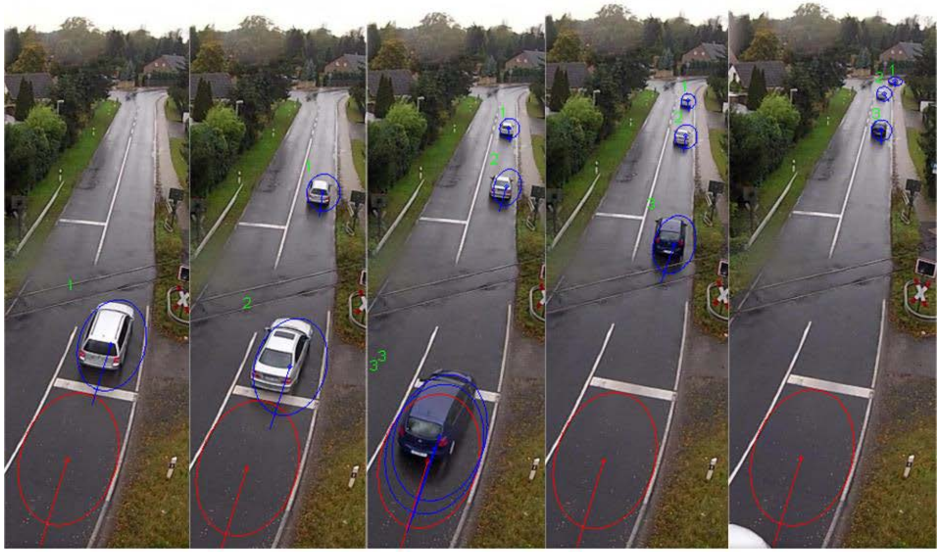
Experiment – 2

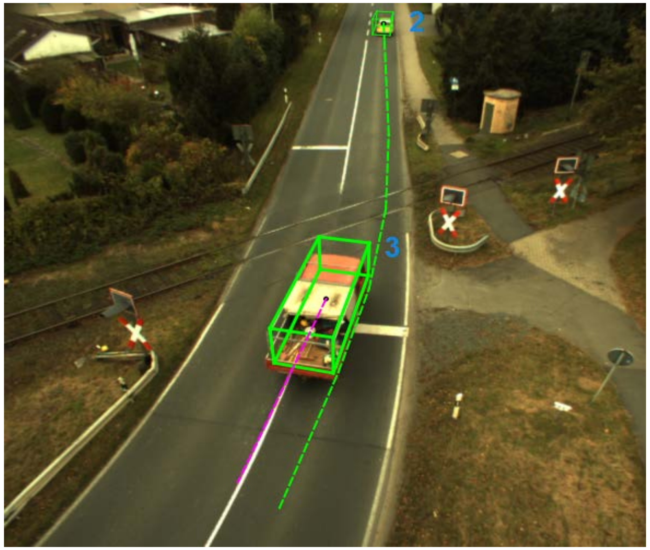
Studying the safety of road users at an unguarded railway crossing

Error of position: σ_x	Error of distance σ_d	Error of velocity σ_v
$0.515\,m$	$0.85\,m$	$1.1\,m/s$

p(TP) = 0.228%, p(FP) = 1.002%, p(TN) = 98.583%, p(FN) = 0.186% (T_0=2.0 s).

TP : FP ratio is **1 : 4.4**



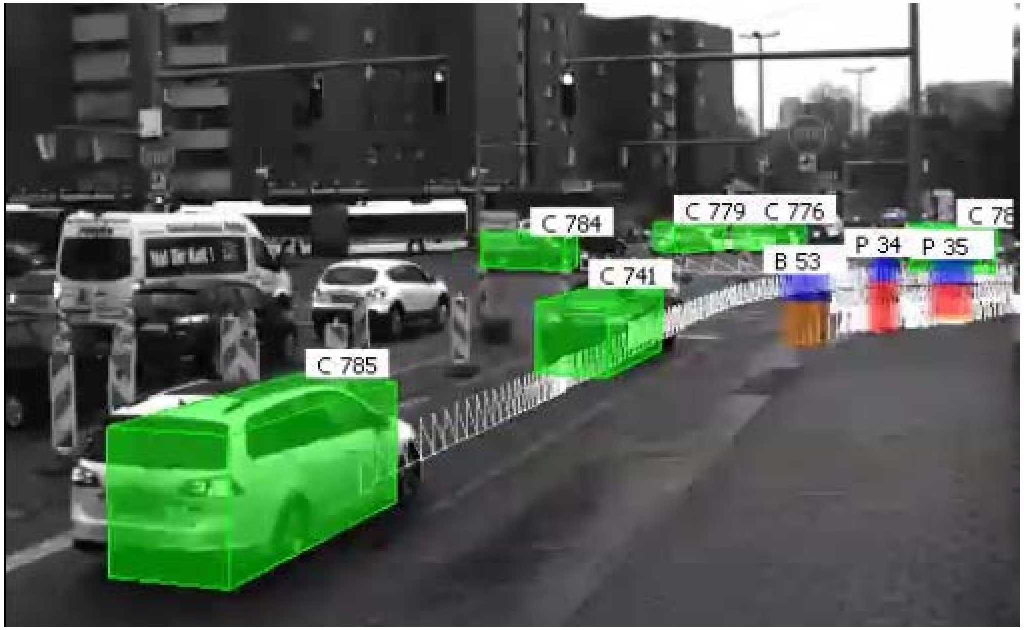


Experiment - 3

Two days evaluated, right-turning traffic (signalized)

- In total **50** situations with TTC<1.0s reported (9 a.m. – 4 p.m.)
- Manual evaluation outcome:
  #TP: 21
  #FP: 29

TP : FP ratio is **1 : 1.4**



Experiment - 3

Two days evaluated, right-turning traffic (signalized)

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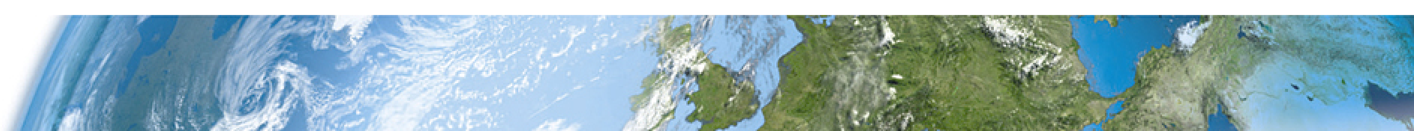
0.1	0.01	2.0	[illegible]	[illegible]	[illegible]	[illegible]

Somewhere between



Summary & Conclusions

Approach predicts/derives error rates for TTC (Note: simplest TTC with constant velocity and thus no deceleration)

Given known object detection accuracies, the scheme predicted false positive rates four to five times higher than the true positive rates.

Evaluation of detected critical situations showed a better ratio, though higher accuracy (closer to sensor).

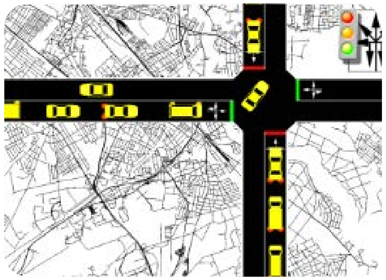
So, approach seems to produce plausible results.

Outlook

1. Apply **more complex path prediction / TTC** (take changing velocity/acceleration into account))

2. Use **other SSM** (TIT, PET, …)

3. Consider distance-dependent error from sensor/object detection



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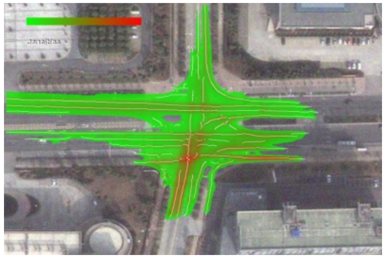

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Based on publication

Leich, Andreas und Kendziorra, Andreas und Saul, Hagen und Hoffmann, Ragna (2016):

Calculation of Error Rates for Detection of Critical Situations in Road Traffic. In: 95th TRB Annual Meeting – Compendium of Papers, 95. Transportation Research Board. TRB Annual Meeting 2016, 10.-15. Jan. 2016, Washington.